PLASMA FLOW SWITCH EXPERIMENTS ON THE PEGASUS FACILITY*

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Abstract

Plasma flow switch experiments conducted on Pegasus have shown that a conducting layer of plasma shunts the load slot preventing efficient switching of current to the load. This effect is seen computationally. The magnitude of the effect depends on the specific parameters of the switch plasma and current level. Computations have also shown that a plasma boundary layer "trap" would effectively remove enough plasma from the inner conductor of the power flow channel so that efficient switching would occur. This plasma trap has been successfully demonstrated when used with a static load. It has not yet been tested with an imploding load.

Introduction

Pegasus is a fast capacitor bank that is presently used in support of the Los Alamos Foil Implosion Program. The bank has a maximum stored energy of 1.5 MJ at 120 kV (±60 kV charge voltage). The capacitance is 216 μF with a total system inductance of 30 nH. Typical operating parameters are a charge voltage of ±44 kV with a peak current into the plasma flow switch (PFS) load of 6.5 MA in 3.3 μs. The quarter cycle time of the bank when fired into the static system inductance is 4 μs. The capacitors are arranged around a circular transmission line in four modules of 36 capacitors each. Each module is switched by solid dielectric switches activated by detonators.

The role of Pegasus in the Los Alamos Foil Implosion Program is an experimental facility for the study of inductive energy storage systems driving plasma radiation sources. Key issues are the requirement for a fast, high-current opening switch and the need for a better understanding of the implosion process. The fast opening switch chosen for investigation is the PFS. Ideally, this switch acts like a conducting washer moving down a coaxial channel. The switch provides a current path that isolates the load from the current until the PFS passes over the load. The load then becomes part of the circuit in (to a first approximation) the transit time of the switch passing over the load (Fig. 1). The PFS used on Pegasus has a velocity of 6-7 cm/μs and has a theoretical switching time of 300 ns for a 2-cm-high load. The geometry of the PFS in the power flow channel (PFC) is shown in Fig. 2.

The PFS dimensions chosen for Pegasus are based on the dimensions of the switch used in the Quick-Fire experiments on the SHIVA Star bank at AFWL[1]. Given our lower current capability, the switch mass is chosen to have the same acceleration as the switch mass used in Quick-Fire. Coaxial dimensions in the PFS "run-down" region are

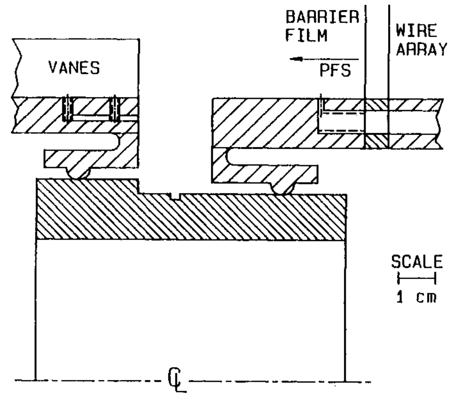

Fig. 1. Plasma flow switch schematic.

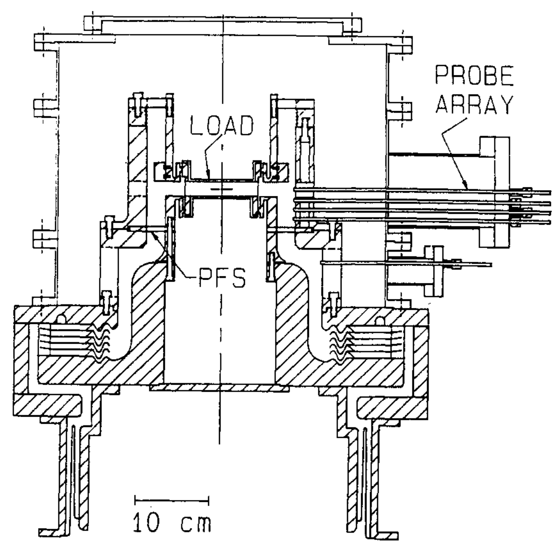

Fig. 2. PFS installed in the power flow channel.

the same (7.7-cm i.d. and 10.2-cm o.d.), and the current is switched into the load 3.8-4 μs after bank initiation. The total switch mass is 40 mg with an equal division of mass in the aluminum wire array and in the 1-micron-thick barrier film. The aluminum wire array is a chordal array of 160 wires, each 0.0025 cm in diameter. When the wire

*Work supported by U.S. Department of Energy.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUN 1991	**N/A**	**-**

4. TITLE AND SUBTITLE
Plasma Flow Switch Experiments On The Pegasus Facility

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Los Alamos National Laboratory P.O. Box 1663 Los Alamos, NM 87545

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**4**	

array mass distribution is combined with the uniform mass distribution of the Mylar barrier film, a $1/R^2$ mass distribution is achieved to within 7%. The barrier film is located 0.63 cm downstream of the aluminum wire array. The aluminum wires initially short the coaxial PFC and provide the initial current path for the capacitor bank. The current rapidly vaporizes the wires forming a plasma behind the barrier film. The barrier film vaporizes about 800 ns later. The barrier film serves to reduce, but not eliminate, precursor currents in the PFC. The plasma is accelerated toward the load by the J x B force of the current and reaches the load in 3.3 μs. The L-dot of the switch causes the bank current to decrease just before switching. The load is a 2500-Å-thick, 2-cm-high, 10-cm-diameter hard-mounted aluminum foil. It is located in a slot 2-cm wide and 2.7-cm deep. "Dummy load" shots, used to study switch characteristics, replace the aluminum foil with a thick-wall aluminum cylinder. This cylinder allows insertion of B-dot probes at the surface of the load.

Experimental Results

The primary diagnostic used in observing the PFS behavior is an array of B-dot probes. The location of the probes in the outer coaxial portion of the PFC is shown in Fig. 2. The probes are typically separated azimuthally to avoid any downstream interactions with each other. The probes are constructed of a single turn formed by bending the inner conductors of small semi-rigid coax (RG 405) back to the shield and attaching the two with a solder joint. The typical area of the probes is 3-5 x 10^{-6} m^2. Typical axial length of the effective probe area is 2-3 mm. The shield of the cable is covered with shrink wrap for insulation and the tip of the probe is protected by inserting it into a quartz jacket filled with epoxy. Many of the probes are re-usable. The probe signals are integrated by 300 μs integrators and transmitted to the screen room over analog fiber optic links with 20 MHz bandwidth where they are recorded on digitizers.

The probes in the outer coaxial electrode of the PFC show the typical current steepening as the plasma sheath progresses down the channel. Early dummy load shots had 4 MA switched into the load (Fig. 3). This was about 70% of the available current and had a rise time of 250-350 ns. Note that the current in the PFC is crowbarred.

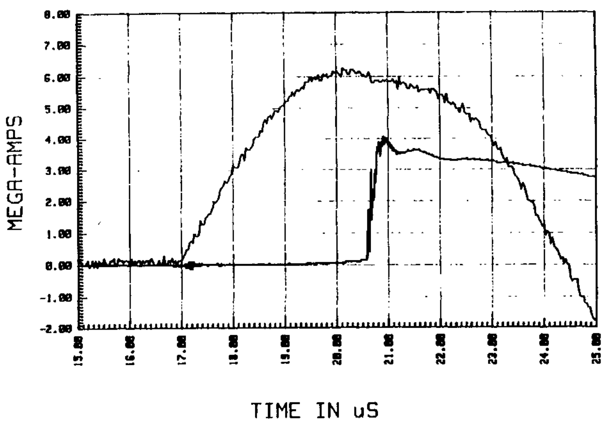

Fig. 3. Bank current (Rogowski) and current switched into a dummy load using a standard PFS configuration.

This occurs when the vacuum insulator flashes over due to the PFC voltage polarity changes. When foils were used as a load, the amount of radiated energy was much less than expected if the drive current were 4 MA. Further investigation of current transfer into the load slot showed only about 2-2.5 MA were being switched into the load slot at radii of less than 4 cm when implosion loads were used. These results are similar to the early AFWL results[2].

Simulations were done on the basic design of the PFS[3] that indicated the load slot was being shunted by a plasma layer laid down on the inner conductor of the PFC by the PFS (see Fig. 4). In Fig. 4, density contours are plotted, and the switch plasma has just crossed the load slot. Ideally, the plasma would move across the load slot in a thin planar slug leaving no mass behind. This bridging of the load slot by the PFS plasma is consistent with the experimental observation that the current switched into the load slot decays with an L/R constant that is long compared with the 20 μs observation time. This current is typically 50% of the current flowing the PFC as indicated by the probes in the outer wall of the PFC. This implies that a fraction of the total current is switched into the load slot, and then the slot is shunted by the plasma. This plasma does not implode because of the trapped magnetic field of the switched current. The plasma layer has also been observed more directly by probes located at radii just inside of and just outside of the load slot.

A computational effort was made to see what modifications to the basic PFS geometry would eliminate the plasma boundary layer. Several "fixes" were tried including a barrier just before the load slot. It was found that a slot cut into the inner conductor of the PFC would effectively trap the boundary layer. This result is displayed in Fig. 5, which again plots density contours of the switch plasma as it is crossing the load slot. The boundary layer is seen to be impacted on the downstream side of the trap, and the load slot is no longer being shorted by a dense plasma.

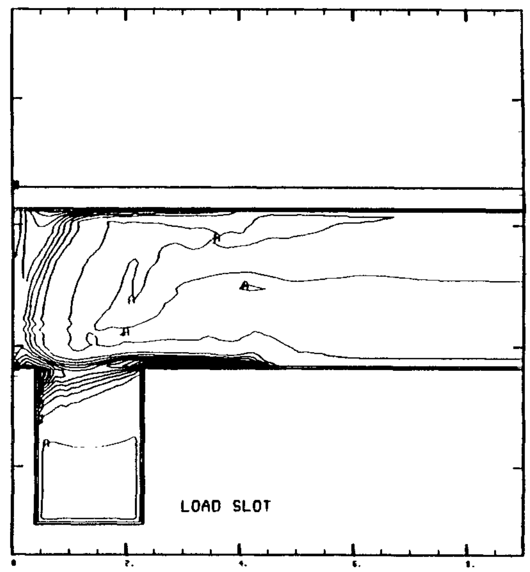

Fig. 4. Density contours showing the PFS boundary layer covering the entrance to the load slot. PFS motion is right to left.

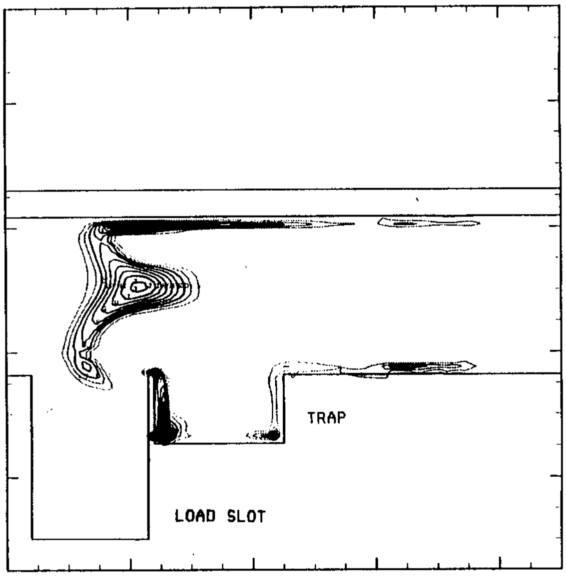

Fig. 5. Density contours with a plasma boundary layer trap machined into the inner conductor of the PFC Just upstream of the load slot.

Experimental tests of this computation consisted of firing a shot without the trap to try and observe the boundary layer and then to repeat the shot with the trap in place. Figure 6 shows the experimental arrangement with the plasma boundary layer trap in place. The trap is immediately to the right of LP1 and LP2 in the figure. The load probe positions were the same in both cases. The load probe currents without the trap are shown in Fig. 7. The 300 ns delay between probes LP1 and LP4 is the transit time of the PFS crossing the load slot (2 cm). Notice the 1 μs time delay in current arriving at LP1 and LP2, which is located at a radius 4 mm less than LP1. This is consistent with a conducting layer between the probes. When flux does penetrate the layer, current arrives within 50 ns at probes LP2 and LP3. Again, the switched current is 4 MA, which is consistent with all of the dummy load shots.

The results of the experiment with the plasma boundary layer trap is shown in Fig. 8. Notice that all of the current flowing at the time of switching is transferred into the load, to within experimental error. The switched current in this case is 5.8 MA.

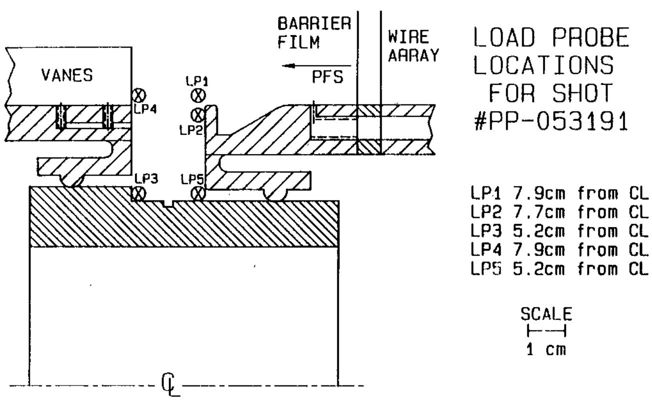

Fig. 6. Load probe locations for probing the effects of the plasma boundary layer and its effect on switching both with and without the boundary layer trap.

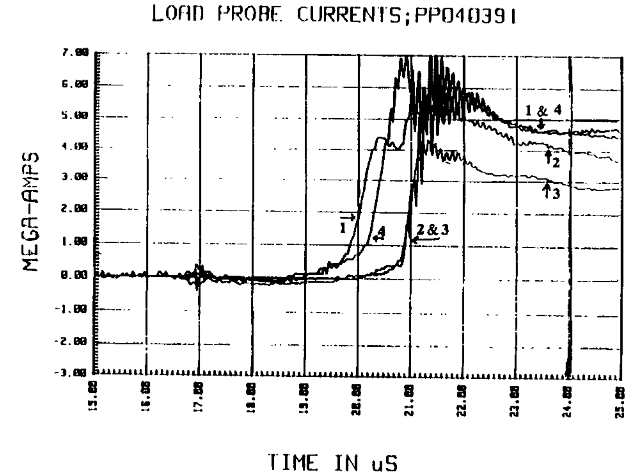

Fig. 7. Load probe currents without the plasma boundary layer trap. Probe numbers correspond to Fig. 6.

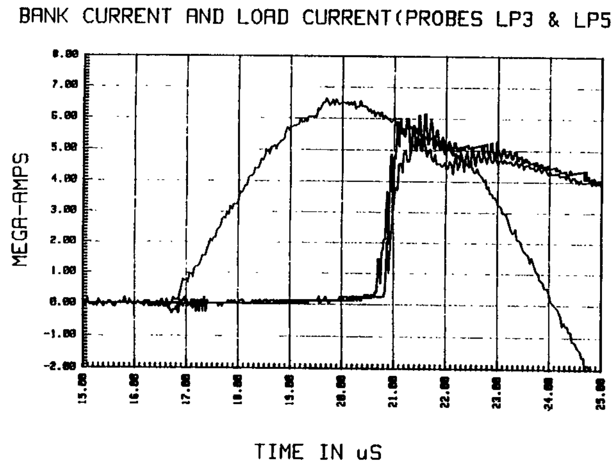

Fig. 8. Bank current and current switched into the load with the plasma boundary layer trap inserted.

Summary

Computations have predicted and experiments have verified that a slot cut into the inner conductor of the PFC effectively traps the plasma boundary layer that the PFS lays down on the inner wall of the PFC in Pegasus experiments. This trap gives a current transfer into the nonimploding load of 90-100% with a risetime of 250-300 ns. At present current levels, this is an average I-dot of 2×10^{13} A/s. Tests using an imploding load with the plasma boundary layer trap are planned for the immediate future.

Acknowledgements

The work of F. Garcia, M. Garcia, and P. Roybal is gratefully acknowledged.

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[3] D. Peterson, et al., these Proceedings.